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(54) **PRESERVING MATRIX SURROUND
INFORMATION IN ENCODED AUDIO/VIDEO
SYSTEM AND METHOD**

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Nov. 14, 2002, now Pat. No. 7,428,440.

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H04S 3/02 (2006.01)
G10L 19/02 (2013.01)
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(2013.01); **G10L 19/02** (2013.01); **G10L 19/167**
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(58) **Field of Classification Search**

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USPC 700/94; 704/500

See application file for complete search history.

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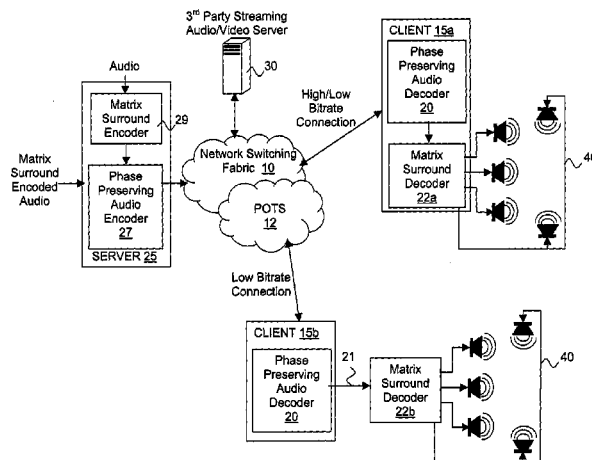
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(57) **ABSTRACT**

A method and apparatus for preserving matrix-surround
information in encoded audio/video includes a receiver
operative to receive matrix-surround encoded audio signals
via a modem, separate the audio signals into a frequency
spectrum having discrete audio frequencies, and determine a
cutoff threshold used to encode the matrix-surround encoded
audio signals. The method and apparatus further includes a
decoder operative to decode a first set of the audio frequencies
below the determined cutoff threshold using a first matrix-
surround preserving audio encoding method and to decode a
second set of audio frequencies above the cutoff threshold
using a second non matrix-surround preserving audio encod-
ing method.

8 Claims, 5 Drawing Sheets



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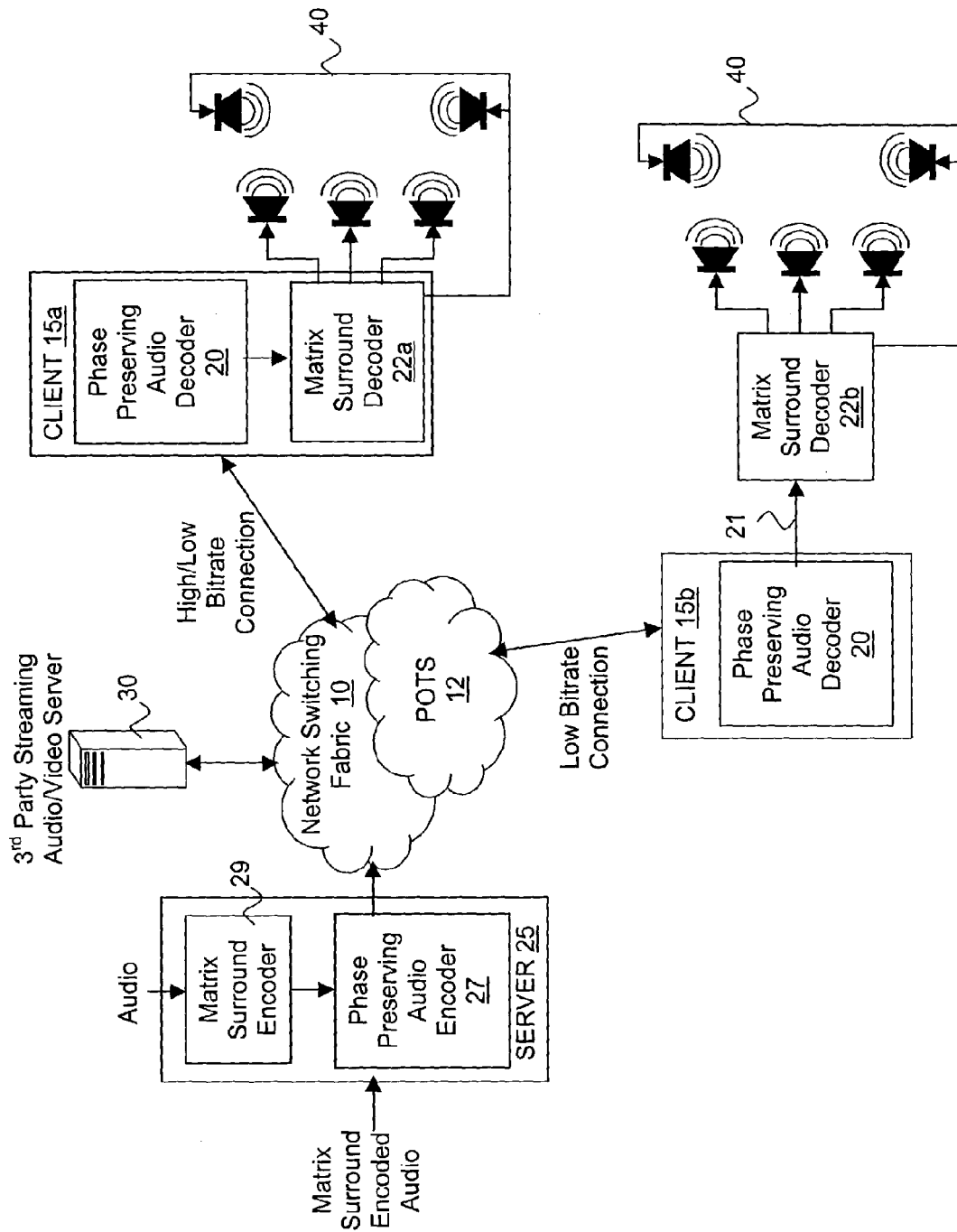


Figure 1

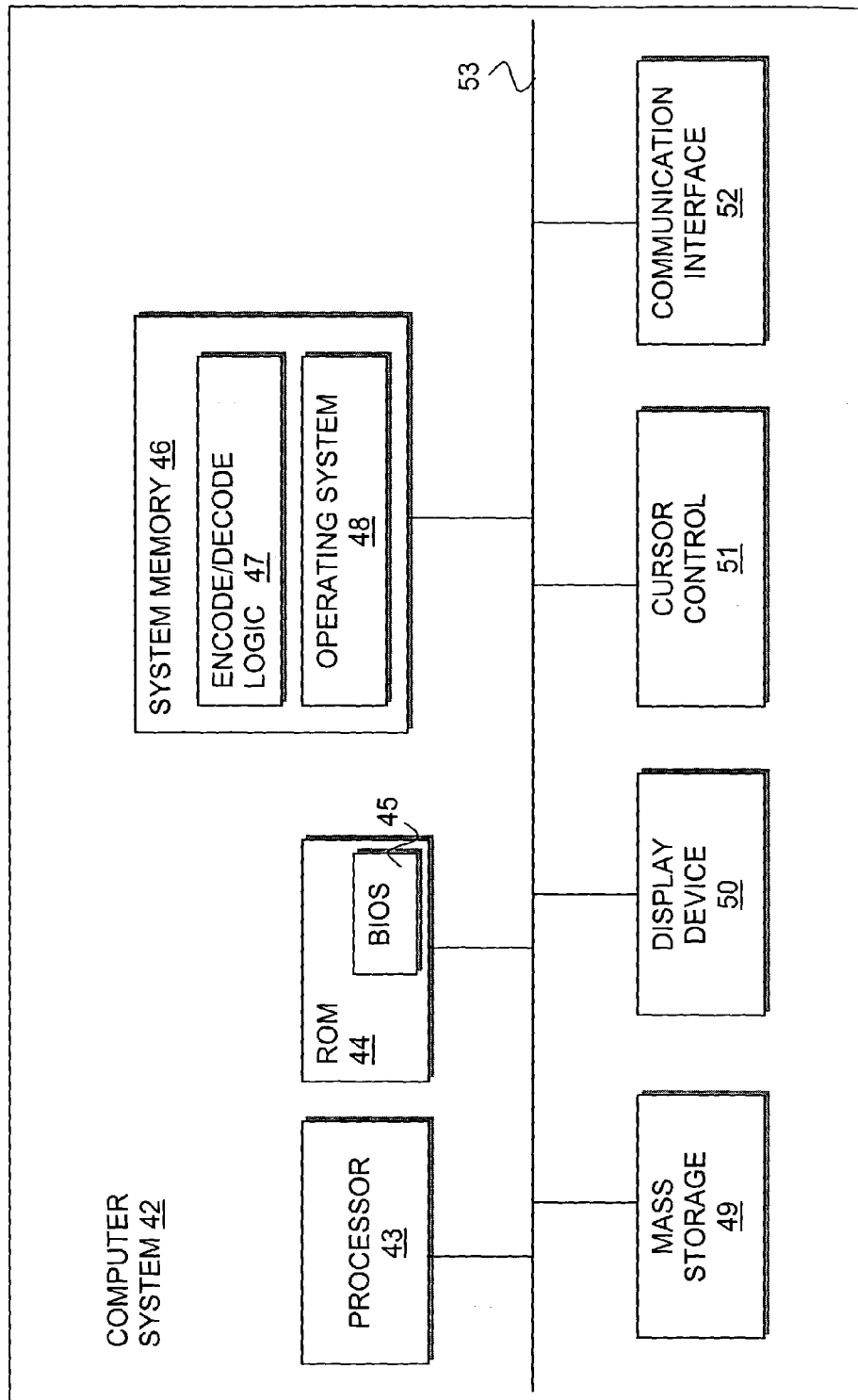


Figure 2

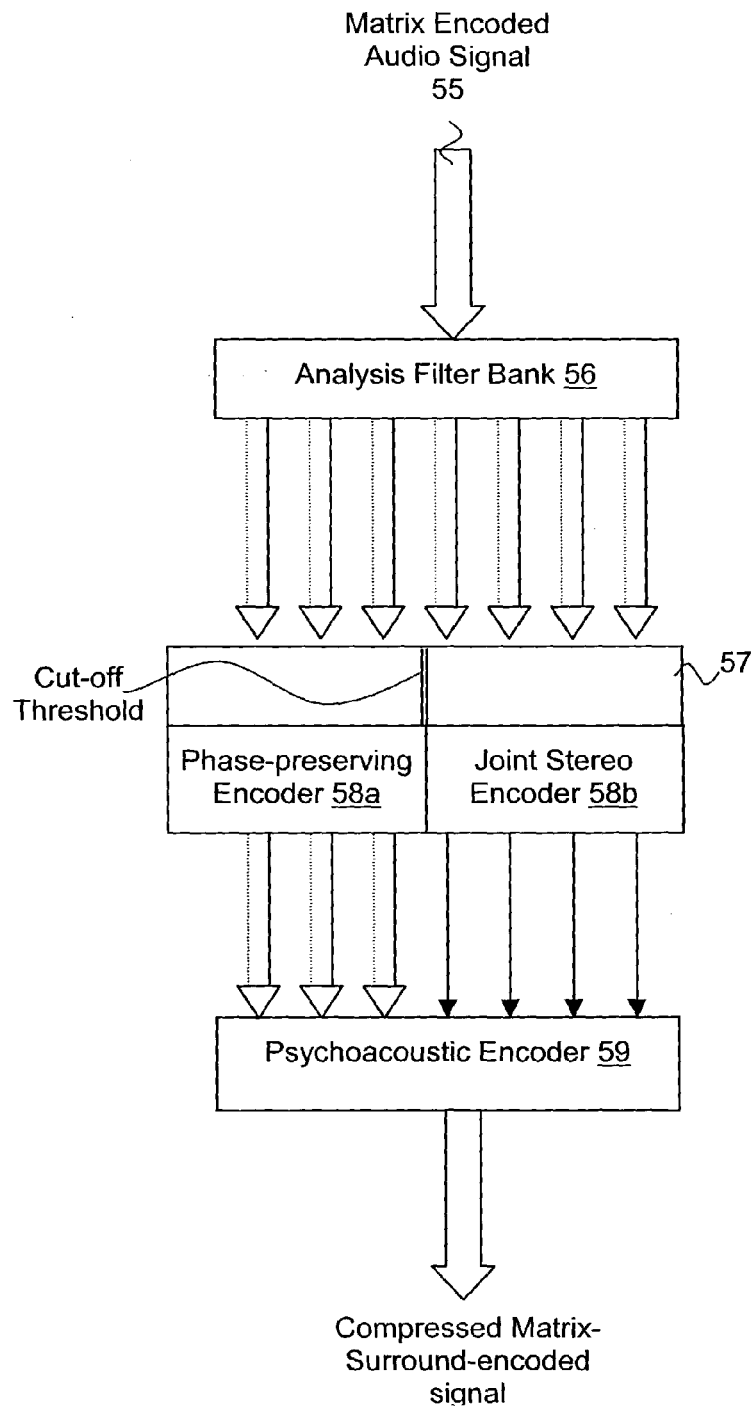


Figure 3

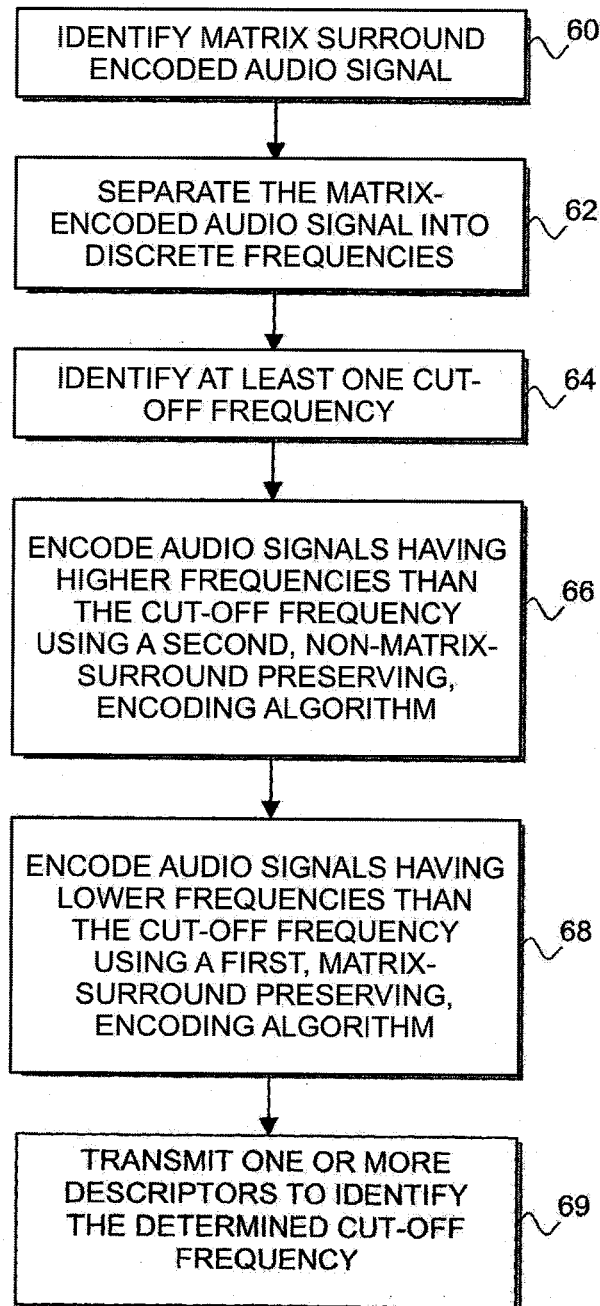


Figure 4

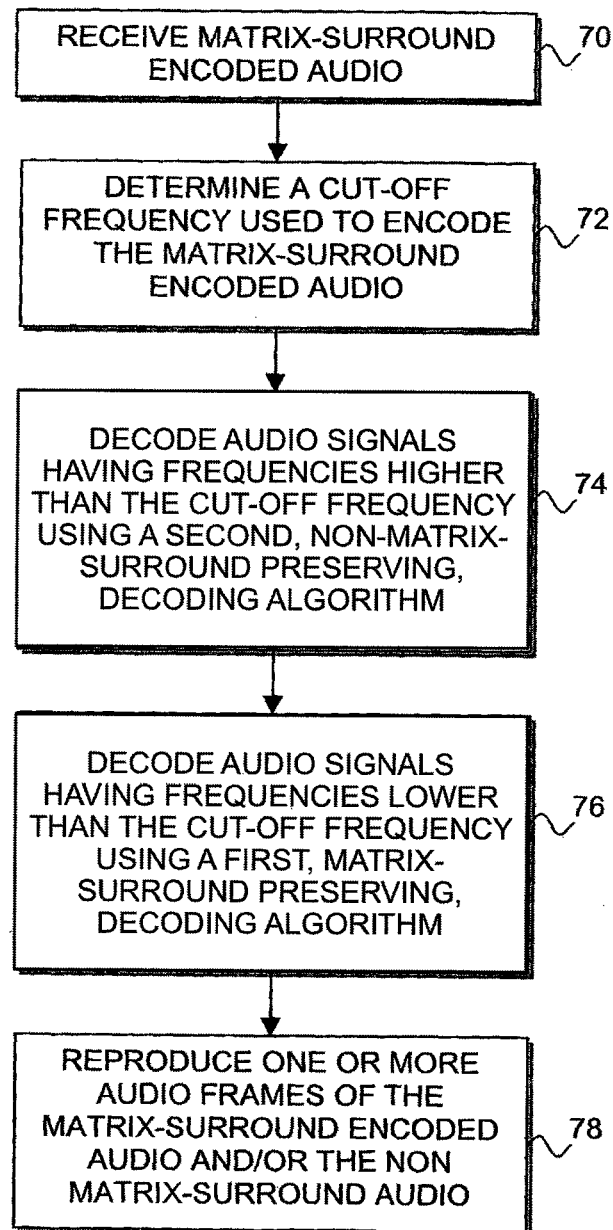


Figure 5

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PRESERVING MATRIX SURROUND INFORMATION IN ENCODED AUDIO/VIDEO SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/235,504, entitled "Preserving Matrix Surround Information in Encoded Audio/Video System and Method", filed Sep. 22, 2008, and naming inventors Wolfgang A. Schildbach and Kenneth Edward Cooke. application Ser. No. 12/235,504 is a continuation of U.S. patent application Ser. No. 10/295,582 (now U.S. Pat. No. 7,428,440), entitled "Method and apparatus for preserving matrix surround information in encoded audio/video", filed Nov. 14, 2002, and naming inventors Wolfgang A. Schildbach and Kenneth Edward Cooke. application Ser. No. 10/295,582 claims priority to U.S. provisional patent application Ser. No. 60/375,289 entitled "Method And Apparatus For Preserving Matrix Surround Information In Streaming Audio/Video", filed Apr. 23, 2002, and naming inventors Wolfgang A. Schildbach and Ken Cooke. The above-cited applications are incorporated herein by reference in their entireties, for all purposes.

FIELD

The present invention generally relates to the field of audio/video coding and decoding. More specifically, the present invention is related to a method of preserving matrix-surround encoded sound in digitally encoded audio/video.

BACKGROUND

In a psychoacoustic audio encoder, coding of low-bitrate stereophonic signals is often achieved by what is referred to as joint-stereo techniques. In its simplest form, instead of transmitting two independent channels, joint-stereo techniques transmit the sum "M" of both channels together with a coefficient "C" that determines the direction in which this signal will be presented at the decoder:

$$L_r = M^* \sin(C), R_r = M^* \cos(C)$$

where L_r and R_r are the left and right channel signals which are reconstructed in-phase with respect to one another. Typically, the audio signal is split into several audio frequency bands and one such coefficient is transmitted per group of frequency bands (e.g. to save bits over transmitting both channels because the coefficient can be heavily quantized). Although joint-stereo techniques may be well-suited for coding of low-bitrate stereophonic signals, they are not particularly well-suited for encoding matrix-surround sound signals as information (such as phase relationships) typically needed by the receiver for matrix-surround sound processing/decoding is not preserved using such joint-stereo techniques. Matrix-surround encoding is essentially an approach to encoding surround sound in which third and sometimes fourth channels of sound are folded into the two front stereo channels and later partially decoded in a reverse operation. The center channel is decoded by using signals common to both left and right channels, whereas the surround channel is decoded by extracting the sounds with inverse waveforms.

As opposed to joint-stereo techniques, dual channel or dual-mono encoding and mid/side coding techniques do tend to preserve information needed for surround sound processing/decoding. Dual channel or dual-mono coding encodes the

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two input channels (i.e. left and right) as separate entities, whereas in mid/side coding, the mid (L+R) channel having a mono component and the side (L-R) channel having a phase component are encoded separately. Unfortunately however, existing surround sound preserving coding techniques are high bandwidth techniques that are not suitable for transmission over low-bitrate connections.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described by way of exemplary embodiments, but not limitations, illustrated in the accompanying drawings in which like references denote similar elements, and in which:

FIG. 1 illustrates an overview of the present invention in accordance with one embodiment;

FIG. 2 illustrates one embodiment of a general-purpose computer system equipped with phase-preserving decoding facilities of the present invention;

FIG. 3 illustrates a functional block diagram of one embodiment of a phase-preserving audio encoder of the present invention;

FIG. 4 illustrates an operational flow diagram of one embodiment of the matrix-surround audio coding process of the present invention; and

FIG. 5 illustrates an operational flow diagram of one embodiment of the matrix-surround audio decoding process of the present invention.

DESCRIPTION

The present invention includes a method and apparatus for compressing matrix-surround encoded audio signals in a surround sound-preserving manner for transmission to a receiver/decoder. Using the methods described herein, matrix-surround information is preserved during an audio compression process, facilitating the transmission of the matrix-surround encoded audio to a receiver/decoder, particularly over low bitrate connections.

In the description to follow, various aspects of the present invention will be described, and specific configurations will be set forth. However, the present invention may be practiced with only some or all aspects of these specific details. In other instances, well-known features are omitted or simplified in order not to obscure the present invention.

The description will be presented in terms of operations performed by a processor based device, using terms such as identifying, receiving, determining, encoding, decoding, and the like, consistent with the manner commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. As is well understood by those skilled in the art, the quantities take the form of electrical, magnetic, or optical signals capable of being stored, transferred, combined, and otherwise manipulated through mechanical, electrical and/or optical components of the processor based device.

Various operations will be described as multiple discrete steps in turn, in a manner that is most helpful in understanding the present invention, however, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

The description repeatedly uses the phrase "in one embodiment", which ordinarily does not refer to the same embodiment, although it may. The terms "comprising", "including", "having", and the like, as used in the present application, are intended to be synonymous.

FIG. 1 illustrates an overview of the present invention in accordance with one embodiment. In the illustrated embodiment, server 25 is endowed with phase-preserving audio encoding logic (hereinafter “phase-preserving encoder”) 27 incorporating the teachings of the present invention. As will be described in further detail below, phase-preserving encoder 27 is equipped to encode (i.e. compress), in a phase-preserving manner, matrix-surround encoded source audio for transmission across network switching fabric 10 and/or POTS 12 to a receiving device via a low bitrate connection. For the purposes of this description, source audio refers to any acoustic, mechanical, or electrical sound waves ranging in frequencies that may fall inside or outside of the range of human hearing. Furthermore, for the purposes of this description, a low bitrate connection may be a connection that provides data throughput rates typically falling within the 44 kbps-96 kbps range. In one embodiment, data throughput rates that do not exceed 96 kbps per second are considered low bitrate connections.

Existing surround sound processors, such as those found in preexisting audio/video equipment, typically do not reconstruct surround information within higher frequencies within the audio frequency spectrum. In accordance with one embodiment of the invention, phase-preserving encoder 27 includes logic to restrict non phase-preserving coding techniques such as joint-stereo coding, to such higher frequencies where existing surround sound processors are not known to reconstruct surround information. More specifically, in one embodiment a cutoff threshold may be identified for which audio signals having frequencies falling below the cutoff threshold are encoded with a first matrix-surround preserving algorithm such as dual-mono or mid/side coding, and audio signals having frequencies falling above the cutoff threshold are encoded with a non matrix-surround preserving algorithm such as joint-stereo coding. For the purposes of this description, the phrase “encoded with a matrix-surround preserving algorithm” refers to the method of compressing matrix-surround encoded audio such that information, such as phase relationships between the various audio channels, needed to reconstruct the matrix-surround audio at a receiver/decoder may be preserved. Likewise, the phrase “encoded with a non matrix-surround preserving algorithm” refers to the method of encoding matrix-surround encoded audio such that information needed to reconstruct the matrix-surround audio at a receiver/decoder may not be preserved. In one embodiment the cutoff threshold may be chosen to be at 7 KHz, however the cutoff threshold may be chosen based upon the nature of the source audio. For example, in audio that contains very little to no matrix-surround encoded audio, the cutoff threshold may be chosen to be at a relatively low frequency since the risk of losing matrix-surround encoded audio information is small. On the other hand, where reproduction of matrix-surround encoded audio by the decoder may be important, a higher cutoff threshold may be chosen so as to preserve a greater amount of matrix encoding information. Accordingly, matrix-surround encoded audio can be transmitted to a receiving client such as client 15a/15b over low bitrate connections without the loss of phase relationships used by receiving client to recreate the surround signal.

Server 25 may be further equipped with matrix-surround encoding logic 29 to generate matrix-surround encoded audio from e.g. three or four-channel audio before it is passed to phase-preserving encoder 27. Matrix-surround encoding logic 29 may represent any of a number of known surround sound encoders, such as DOLBY SURROUND™ and

DOLBY PROLOGIC SURROUND™ available from Dolby Laboratories, Inc. of San Francisco, Calif., and as such will not be described further. Once the matrix-surround encoded audio is further encoded for transmission by phase-preserving encoder 27, server 25 transmits the encoded matrix-surround audio to a receiving device, such as clients 15a/15b, via network switching fabric 10 and/or POTS 12. In one embodiment, server 25 transmits the encoded matrix-surround audio to a receiving device in the form of a bit stream.

Network switching fabric 10 represents one or more local and/or wide area networks such as the Internet, whereas POTS 12 represents plain old telephone service facilities. In one embodiment, the matrix-surround encoded audio may be transmitted to clients 15a/15b by server 25 in response to a download request initiated by clients 15a/15b. However in other embodiments, the matrix-surround encoded audio may instead be stored by third-party server 30, which similarly receives download requests initiated by clients 15a/15b. In one embodiment, the matrix-surround encoded audio may be delivered to client 15b via a low bit-rate connection, such as that provided by e.g., a 56 kbps modem connection to POTS 12. In one embodiment of the invention, the matrix-surround encoded audio may be delivered to clients 15a/15b via a streaming data connection, where at least a portion of the compressed matrix surround encoded audio may be rendered at the client before all of the audio is received by the client. In one embodiment, the streaming data may be received by clients 15a/15b via at least one analog MODEM device.

Clients 15a/15b are both equipped with phase-preserving audio decoding logic (hereinafter “phase-preserving decoder”) 20 incorporating the teachings of the present invention. In one embodiment of the invention, phase-preserving decoder 20 receives the compressed matrix-surround encoded audio signals (e.g. from server 25), determines the cutoff threshold used (e.g. by phase-preserving encoder 27) during the encoding process to compress the matrix-surround encoded audio signals, and decodes (i.e. decompresses) the matrix-surround encoded audio signals based upon the cutoff threshold. In one embodiment, phase-preserving decoder 20 decodes a first set of audio frequencies below the cutoff threshold using an algorithm that is complementary to the first matrix-surround preserving audio encoding algorithm, and decodes a second set of audio frequencies above the cutoff threshold using an algorithm that is complementary to the second non matrix-surround preserving audio encoding algorithm.

Once phase-preserving decoder 20 has decompressed the matrix-surround encoded audio, the resulting output signals are passed to matrix-surround decoders 22a/22b for further decoding into the original three or more discrete audio channels (e.g. as encoded by matrix-surround encoder 29 or provided to phase-preserving encoder 27) for play out by speakers 40. The matrix-surround decoder may be integrated within the receiving client, such as with the case of client 15a, or the matrix-surround decoder may be integrated into a separate audio/video component, such as with client 15b. In the event matrix-surround decoder 22 may be integrated into a separate pre-existing audio/video component, the discrete audio signals output by phase-preserving decoder 20 may be transmitted to matrix-surround decoder 22b via patch cables 21. Accordingly, the present invention is able to leverage upon the very large number of pre-existing consumer audio/video systems that include a matrix-surround based audio decoder, such as those capable of decoding DOLBY SURROUND™ and/or DOLBY PROLOGIC™ SURROUND encoded audio.

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Each of clients **15a/15b** and server **25** are intended to represent a general purpose computing device which may include but is not limited to a wireless mobile phone, palm sized personal digital assistant, notebook computer, desktop computer, set-top box, game console, server, and so forth. FIG. 2 illustrates one embodiment of such a general-purpose computer system equipped with phase-preserving decoding facilities of the present invention. As shown, example computer system **42** includes processor **43**, ROM **44** including basic input/output system (BIOS) **45**, and system memory **46** coupled to each other via "bus" **53**. Also coupled to "bus" **53** are non-volatile mass storage **49**, display device **50**, cursor control device **51** and communication interface **52**. During operation, system memory **46** includes working copies of operating system **48** and encode/decode logic **47** of the present invention.

Except for the teachings of the present invention as incorporated herein, each of these elements is intended to represent a wide range of these devices known in the art, and otherwise performs its conventional functions. For example, processor **43** may be a processor of the Pentium® family of processors available from Intel Corporation of Santa Clara, Calif., which performs its conventional function of executing programming instructions of operating system **48** and encode/decode logic **47** of the present invention. ROM **44** may be EEPROM, Flash and the like, while memory **46** may be SDRAM, DRAM and the like, from semiconductor manufacturers such as Micron Technology of Boise, Id. Bus **53** may be a single bus or a multiple bus implementation. In other words, bus **53** may include multiple properly bridged buses of identical or different kinds, such as Local Bus, VESA, ISA, EISA, PCI and the like.

Mass storage **49** may represent disk drives, CDROMs, DVD-ROMs, DVD-RAMs and the like. Typically, mass storage **49** includes the permanent copy of operating system **48** and encode/decode logic **47**. The permanent copy may be downloaded from a distribution server through a data network (such as the Internet), or installed in the factory, or in the field. For field installation, the permanent copy may be distributed using one or more articles of manufacture such as diskettes, CDROM, DVD and the like, having a recordable medium including but not limited to magnetic, optical, and other mediums of the like.

Display device **50** may represent any of a variety of display types including but not limited to a CRT and active/passive matrix LCD display, while cursor control **51** may represent a mouse, a touch pad, a track ball, a keyboard, and the like to facilitate user input. Communication interface **52** may represent a modem device (including but not limited to an analog/telecommunications modem, digital/cable modem, a wireless modem or any other modulator/demodulator device), an ISDN adapter, a DSL interface/modem, an Ethernet or Token ring network interface and the like.

As those skilled in the art will appreciate, the present invention may also be practiced without some of the above-enumerated elements, or with additional elements without departing from the spirit and scope of the invention.

FIG. 3 is a functional illustration of one embodiment of a phase-preserving audio encoder of the present invention. As shown, full-bandwidth matrix-surround encoded audio signal **55** may be first passed through an analysis filter bank **56** to separate the matrix-surround encoded audio signal into discrete frequency bands. Next, cutoff frequency logic **57** determines a cutoff threshold identifying the lowest frequency band of the discrete frequency bands to be joint-stereo encoded cutoff. In accordance with the illustrated embodiment, audio signals having a higher frequency than that indi-

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cated by the cutoff threshold are passed through Joint Stereo encoder **58b**, before being passed through Psychoacoustic encoder **59**, whereas audio signals having frequencies falling below the cutoff threshold are passed directly or through a phase preserving processing encoder **58a** to Psychoacoustic encoder **59**. In one embodiment, a descriptor that identifies a cutoff threshold below which joint-stereo (i.e. non phase-preserving) methods are not to be applied may be transmitted from phase-preserving encoder **27** to phase-preserving decoder **20** to facilitate reproduction of the matrix-surround encoded audio at client **15a/15b**. Such a descriptor may be represented by one or more bit patterns that are transmitted to phase-preserving decoder **20** in conjunction with or independent from the matrix-surround encoded audio. In one embodiment, the determination as to the cutoff threshold for which joint-stereo methods are to be applied may be made dynamically on a frame-by-frame basis. Accordingly, it may be possible to dynamically tune the audio encoding based at least in part upon the audio content. In accordance with one embodiment of the invention, the upper bound (i.e. highest single frequency or range of frequencies) of the frequency spectrum to be encoded varies in proportion to the amount the cutoff frequency varies. In one embodiment, as the cutoff frequency increases, the upper bound of the frequency spectrum to be encoded decreases. For example, if the cutoff threshold of a given frequency spectrum increases from 7 KHz to 8 KHz, the upper bound of a frequency spectrum to be encoded may decrease from 15 KHz to 12 KHz in order to compensate for the additional surround information (i.e. that between 7 KHz and 8 KHz) that needs to be encoded.

FIG. 4 illustrates an operational flow diagram illustrating one embodiment of the matrix-surround audio coding process of the present invention. To begin, a matrix-surround encoded audio signal is first identified, block **60**, and the audio signal may be separated into discrete frequency bands, block **62**. Next, a cutoff threshold may be identified yielding a first group of frequencies above the cutoff frequency and a second group of frequencies below the cutoff threshold, block **64**. Those audio signals having higher frequencies than that indicated by the cutoff threshold are encoded using a second non matrix-surround encoding (i.e. a non phase-preserving encoding) algorithm, block **66**, whereas those audio signals having lower frequencies than that indicated by the cutoff threshold are encoded using a first matrix-surround encoding (i.e. a phase-preserving encoding) algorithm, block **68**. In one embodiment, audio signals having higher frequencies than that indicated by the cutoff threshold are encoded using intensity stereo coding techniques, while audio signals having lower frequencies than that indicated by the cutoff threshold are encoded using either dual-mono or MS Coding (i.e. mid-side coding). Finally, one or more descriptors identifying the determined cutoff threshold are transmitted to the recipient along with the matrix-surround encoded audio, block **69**.

FIG. 5 illustrates an operational flow diagram illustrating one embodiment of the matrix-surround audio decoding process of the present invention. The process begins at block **70** with matrix-surround encoded audio being received. The cutoff threshold that was identified during the encoding process (e.g. of FIG. 3) may then be determined at block **72**. In one embodiment, the cutoff threshold may be encoded within the matrix-surround encoded audio as a predetermined bit-pattern recognizable by phase-preserving decoder **20**. Audio signals having higher frequencies than the cutoff threshold are then decoded using a first non matrix-surround preserving algorithm, block **74**, whereas audio signals having lower frequencies than the cutoff threshold are decoded using a second matrix-surround preserving algorithm, block **76**. This then

facilitates the reproduction/rendering of one or more audio frames of the matrix-surround encoded audio and/or non matrix-surround encoded audio, block 78.

EPILOG

While the present invention has been described in terms of the above-illustrated embodiments, those skilled in the art will recognize that the invention may not be limited to the embodiments described. The present invention can be practiced with modification and alteration within the spirit and scope of the appended claims. Thus, the description is to be regarded as illustrative instead of restrictive on the present invention.

The invention claimed is:

1. A method of encoding matrix-surround-encoded audio for transmission over a low bitrate connection that is less than about 96 kbps, comprising:

identifying a source audio content comprising matrix-surround-encoded audio;

separating said source audio content into a frequency spectrum having a plurality of discrete audio frequencies;

determining a frequency cutoff threshold;

encoding a first set of the plurality of audio frequencies below said frequency cutoff threshold using a matrix-surround-preserving audio encoding method including dual-mono or mid/side coding; and

encoding a second set of the plurality of audio frequencies above said frequency cutoff threshold using a non-matrix-surround-preserving audio encoding method including joint-stereo coding.

2. The method of claim 1, wherein said frequency cutoff threshold is determined based at least in part on descriptive information associated with said source audio content.

3. The method of claim 1, wherein said frequency cutoff threshold is determined based at least in part on the content of said source audio content.

4. An apparatus comprising a processor to execute instructions; a communication interface; and a memory device communicatively coupled to the processor and communication interface and having stored thereon a plurality of instructions, which when executed by said processor, operate to:

identify a source audio content comprising matrix-surround-encoded audio;

separate said source audio content into a frequency spectrum having a plurality of discrete audio frequencies;

determine a frequency cutoff threshold;

encode a first set of the plurality of audio frequencies below said frequency cutoff threshold using a matrix-surround-preserving audio encoding method including dual-mono or mid/side coding; and

encode a second set of the plurality of audio frequencies above said frequency cutoff threshold using a non-matrix-surround-preserving audio encoding method including joint-stereo coding.

5. A non-transitory computer-readable medium including a plurality of instructions stored thereon, which when executed by a processor, cause a computing device to:

identify a source audio content comprising matrix-surround-encoded audio;

separate said source audio content into a frequency spectrum having a plurality of discrete audio frequencies;

determine a frequency cutoff threshold;

encode a first set of the plurality of audio frequencies below said frequency cutoff threshold using a matrix-surround-preserving audio encoding method including dual-mono or mid/side coding; and

encode a second set of the plurality of audio frequencies above said frequency cutoff threshold using a non-matrix-surround-preserving audio encoding method including joint-stereo coding.

6. A method of decoding matrix-surround-encoded audio, comprising:

identifying a bit stream comprising matrix-surround-encoded audio;

decoding said bit stream into a frequency spectrum having a plurality of discrete audio frequencies;

determining a frequency cutoff threshold;

decoding a first set of the plurality of audio frequencies below said frequency cutoff threshold using a matrix-surround-preserving audio decoding method including dual-mono or mid/side coding; and

decoding a second set of the plurality of audio frequencies above said frequency cutoff threshold using a non-matrix-surround-preserving audio decoding method including joint-stereo coding.

7. An apparatus comprising a processor to execute instructions; a communication interface; and a memory device communicatively coupled to the processor and communication interface and having stored thereon a plurality of instructions, which when executed by said processor, operate to:

identify a bit stream comprising matrix-surround-encoded audio;

decode said bit stream into a frequency spectrum having a plurality of discrete audio frequencies;

determine a frequency cutoff threshold;

decode a first set of the plurality of audio frequencies below said frequency cutoff threshold using a matrix-surround-preserving audio decoding method including dual-mono or mid/side coding; and

decode a second set of the plurality of audio frequencies above said frequency cutoff threshold using a non-matrix-surround-preserving audio decoding method including joint-stereo coding.

8. A non-transitory computer-readable medium including a plurality of instructions stored thereon, which when executed by a processor, cause a computing device to:

identify a bit stream comprising matrix-surround-encoded audio;

decode said bit stream into a frequency spectrum having a plurality of discrete audio frequencies;

determine a frequency cutoff threshold;

decode a first set of the plurality of audio frequencies below said frequency cutoff threshold using a matrix-surround-preserving audio decoding method including dual-mono or mid/side coding; and

decode a second set of the plurality of audio frequencies above said frequency cutoff threshold using a non-matrix-surround-preserving audio decoding method including joint-stereo coding.

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